Elevated Haze over Phoenix – An Impact on Aircraft Acceptance Rates at Sky Harbor International Airport

Alberta Vieira
CWSU ZAB, Albuquerque, NM

Introduction

As of 2005, Phoenix Sky Harbor International Airport remained the fifth busiest airport in the U.S. Phoenix accepts 72-76 flights an hour on a clear day with no visibility or weather restrictions. In situations with visibilities diminished to less than 3 miles, instrument landings are required. Under these reduced visibility situations about half the number of aircraft can be accepted or allowed to land at the airport. Traffic becomes backed up for miles, which wastes fuel and time. The workload increases for air traffic controllers because planes have to stay in the air longer before being able to land. A problem like haze can cause a domino effect of traffic problems across the United States.

Haze can restrict surface visibility, but in the cases studied here, no change in visibility was reported in the surface observations. However, haze aloft can also be a significant problem, and is not measured by routine surface observations. When haze is present aloft, slantwise visibilities through the haze layer can be noticeably reduced, affecting the approach phase of aircraft and reducing the acceptance rates. Reports of elevated haze are generally received only via pilot reports, or PIREPs. In this study, the significant parameters that influence poor slant range visibilities due to haze are investigated.

Background Information

According to the Pilot Controller Glossary, Arrival Acceptance Rate (AAR) is defined as "the dynamic parameter specifying the number of arriving aircraft which an airport or airspace can accept from the ARTCC (Air Route Traffic Control Center) per hour." The AAR is used to calculate the desired interval between successive arrival aircraft. Phoenix has an AAR of 72 aircraft on a clear day.

The city of Phoenix is located in an area of complex terrain. Fig. 1 depicts features around the Phoenix area. Phoenix is located within an east-west valley that drains to the west. The highest terrain is located north and east of the city. The Phoenix airport is on the southeast side of the city, and within the bowl-type terrain surrounding the city. In the early morning hours, the wind often drains through Phoenix from the east mountain area. This drainage flow transports particulates from the burning of fossil fuels, carbon particles from wildfires, and dust from the Salt River bed into the Phoenix metropolitan area. As the drainage wind diminishes, the particulates stagnate over the metropolitan area. By midday, the wind direction often returns to westerly flow, clearing out the atmospheric particulates.

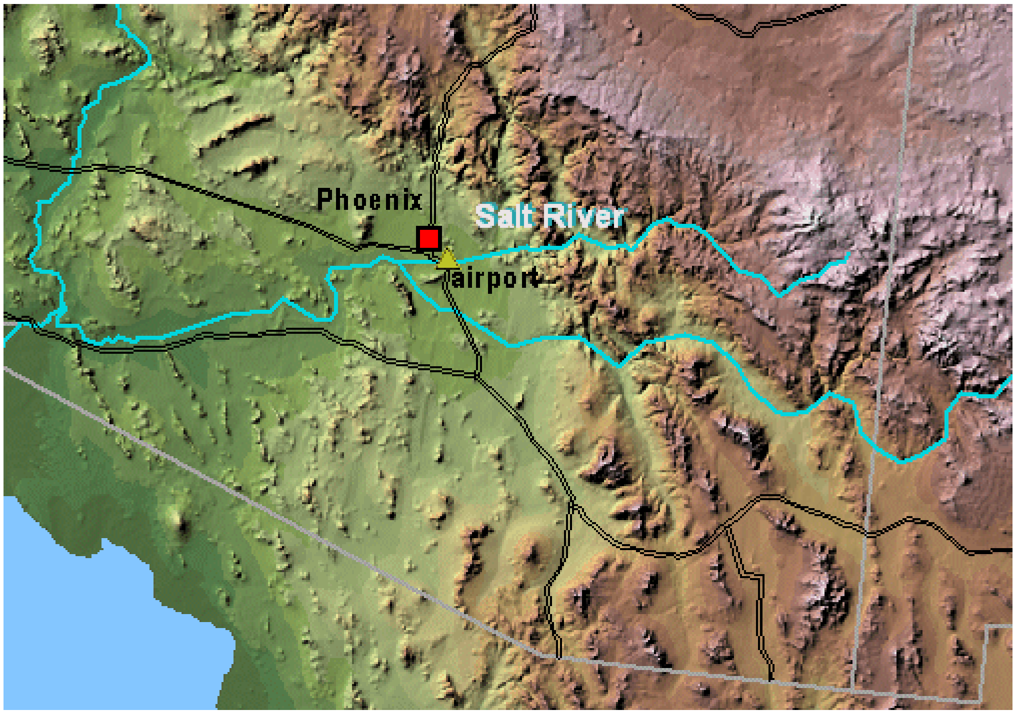

Figure 1. Topographic map of the Phoenix (PHX) area.

Inversions often develop over the Phoenix area. These inversions trap any pollution in the area creating a haze layer beneath the inversion. Phoenix is generally dry, but if sufficient water vapor exists to produce wet haze, sunlight would easily be reflected by the haze causing visual problems for pilots needing to see the airport. Under these conditions the horizontal visibility might be 7 miles or greater, but pilots will often experience a slant range visibility of less than 3 miles. Runways in Phoenix were built in an east-west configuration. It must be noted that the runways in Phoenix were built to accommodate the prevailing winds which are westerly. Visibility problems from haze were not a factor with this decision.

The reduction in slant range visibility due to haze is most often a problem in the morning hours, bringing the AAR down to a 48 or 32 rate depending on severity of the haze. During the day, the inversion may mix out. Additionally, cloud cover can block the sun's rays eliminating the visibility restriction. During the night, the lights along the runways are able to penetrate the haze layer. Under these conditions, a return to a 72 AAR occurs.

In the winter of 2004-2005 elevated haze was a somewhat common occurrence in Phoenix. The frequency of reductions in surface visibility due to smoke and haze (combined) have been documented and generally are considered (by Phoenix observers) to be rare. The reductions are most likely to occur during November, December, and January when diurnal cooling is strongest. However, details of elevated haze resulting in slant range visibility reductions have not been documented. The purpose of this study is to identify the values of significant parameters that can be responsible for slant range visibility problems due to haze in Phoenix.

Methodology

Completing a study on the occurrence of elevated haze is difficult, in part because the observed haze will not be reported by a surface observation. Instead, pilot reports are generally the only indication that a restriction in visibility exists. During the winter months of 2004/2005, on days when pilots reported low visibility due to haze or when haze conditions were expected to exist in Phoenix, various data were collected. Significant haze conditions likely occurred on other days but unless staff at the ZAB CWSU (the Albuquerque Center Weather Service Unit of the Air Route Traffic Control Center) were aware of the conditions data were not collected. Data saved from the elevated haze events included pilot reports (PIREPs), surface observations, analyses at mandatory pressure levels, radiosonde observations, and model soundings.

A variety of data were collected for several haze events, as well as for three days on which elevated haze was expected but did not occur. Phoenix does not take raob observations during the winter months so an ETA model generated sounding was collected from the Weather and Radar Processor or WARP workstation. The model sounding was not saved for the first two events in early December. Soundings from the next closest raob site, Tucson were also collected. The soundings were used to study stability, including inversions, and vertical wind profiles. Analyses were archived to document wind patterns at the surface, 850, 700, and 500 mb. These data were examined to see if a synoptic regime could be identified for the haze events. Temperatures at the surface were examined to determine thresholds for haze development and dissipation. Dew point depressions were noted at the surface from Phoenix observations and extracted from the Tucson sounding from the surface to 800 mb to note the depth of the moisture.

Wind speed observations for the day before each event were looked at to identify a wind events which could affect the amount and distribution of atmospheric particulates which could contribute to the typical daily haze. Particulate concentrations were obtained to see if the values were higher than normal.

Results

Data described above were collected on eight days during the winter months of 2005-2006. Of these eight days, reports of restrictions in slant range visibilities were received on five. On the three non-event days, an elevated layer of haze was anticipated but visual problems were not reported. Data from all eight days are shown in Tables 1 and 2, with the five haze event days listed at the top.

Moisture, Winds, and Synoptic Pattern

Information on moisture and winds are listed in Table 1. Model soundings for Phoenix were only available on four of the five event days. For three of these days, dew point depressions (T-Td) at 850 mb were less than 10 degrees C, while at the surface the dew point depression was 7C or less in the four cases for which observations were available. On December 10, 2005, the sounding was very dry just above the moist surface. The Tucson sounding for the same day was also dry near the surface.

Surface winds were light east winds (less than 9 kt) or calm for all event days. Winds did not exceed 10 kt at 850 mb or 15 kt at 700 mb. In extreme drought situations when winds have been in excess of 25 kt for 3 hours or longer and have been followed by calm conditions, dust combined with smoke particulates can be left in large concentrations. These concentrations along with an inversion are perfect for a thick haze layer if the winds at and near the surface remain light. In all of these events the average speeds the day before the events were less than 10 kt, while peak gusts were less than 17 kt.

Table 1. Data from Phoenix Haze Events

Date	PHX Surface Temp Before Clearg °C	PHX Surface T-Td °C	PHX 850 mb T-Td °C at 2Z	PHX Surface Wind kt (Avg)	PHX 850 mb Wind kt (12Z)	PHX 700 mb Wind kt (12Z)	Moist Sndg SFC – 800 mb PHX/ TUS
08 Dec 04	#	#	Not Avbl	calm	NA	NA	NA/Yes
09 Dec 04	14	4	NA	> 6 / East	NA	NA	NA/Yes
10 Dec 04	11	3	20	< 7 / E	NA	< 15	No/No
22 Jan 05	18	6	8	< 6 / E	< 10	< 15	Yes/Yes
14 Feb 05	14	4	4	< 7 / E	< 10	< 15	Yes/Yes
11 Dec 04	*	*	25	calm	< 10	< 10	No/No
05 Feb 05	*	*	NA	NA	~<10	~<10	NA/Yes
26 Feb 05	*	*	7	calm	< 5	< 10	Yes/Yes

# Indicates problem haze with an unknown time of clearing.
* Indicates a non-haze problem days.

Next, 500 mb and mean sea level analyses were compared, to determine if the haze events occurred with a similar synoptic pattern. Figure 2 shows a low south of Arizona or over the Gulf of California. There is weak east flow at 500 mb. The first three events occurred on consecutive days in early December, 2004. An upper level trough axis was just east of Arizona on the first day (Fig. 3), with high pressure building over the western states the

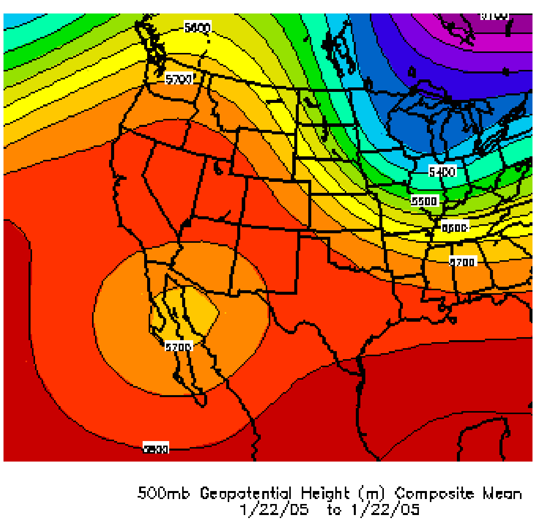

Figure 2. 500 mb Geopotential height (m) composite mean for 22 Jan 05.

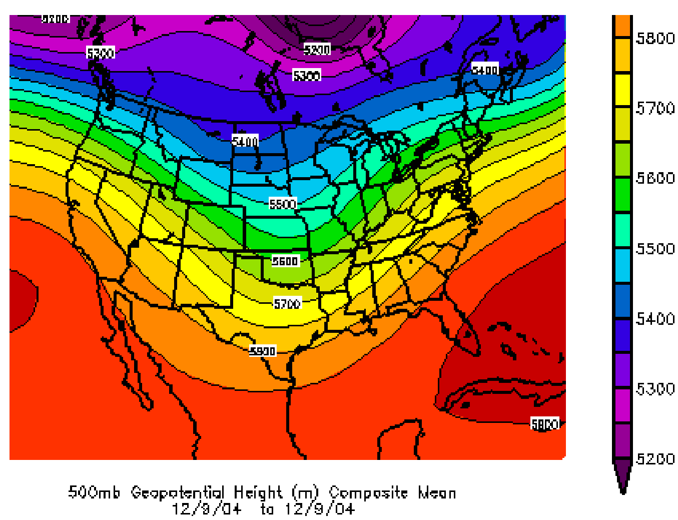

Figure 3. 500 mb Geopotential height (m) composite mean for 09 Dec 04.

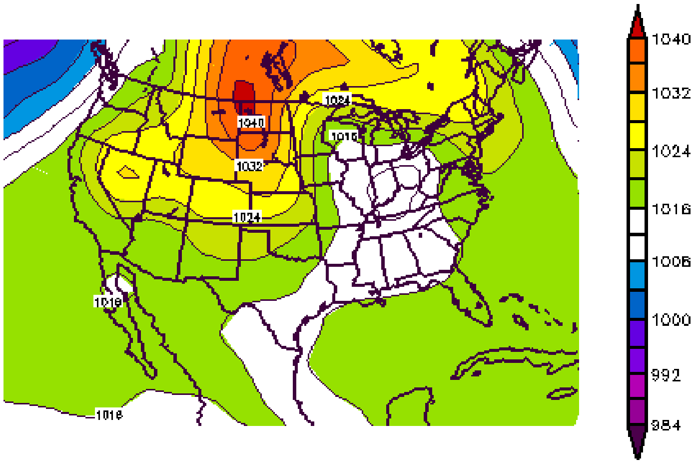

Figure 4. Surface pressure (mb) composite mean for 22 Jan 05.

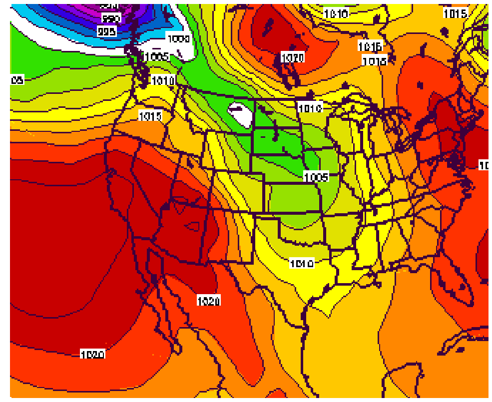

Figure 5. Surface pressure (mb) composite mean for 09 Dec 04.

following two days. West then northwest flow was noted at 500 mb with these events. Another event was associated with weak ridging and westerly flow. In these four cases the 500 mb wind speeds were less than 50 kt over Arizona. It appears as though the pattern at 500 mb is not important, except for the absence of a strong gradient. At the surface, weak pressure gradients were noted in 4 of the 5 cases, supporting the light drainage winds listed in Table 1 (Fig. 4 and 5)

For all five events, no precipitation was recorded on the days just prior to the reported haze. It is possible that rain may have fallen in the surrounding area because in all but one of the soundings significant moisture existed to at least 800 mb. (Surface pressure at Phoenix, uncorrected for sea level is about 975 mb.) At Tucson four of the five events had a moist atmosphere from the surface to 700 or 800 mb.

Of the soundings generated from model data for Phoenix, all had inversions near 950 mb, or near the surface, which is normal. These soundings were interpolated data and likely to be smoothed out. Tucson's soundings were obtained for each of the days. As shown in Table 2 (next page), all had an inversion and moist layers from surface to at least 800 mb. These soundings also showed an inversion at two or three other levels. Figure 6 is the sounding for Tucson for January 22, 2005. Note the several inversions, and moist layers. Assuming similar atmospheric conditions existed at Phoenix as in Tucson it would make sense that moisture and haze may have existed within the inversions at Phoenix.

Table 2. Details of elevated inversions above the surface inversions at Tucson.

Date, Day	Level(s) of Inversions	Depth of each Inversion	Temp Diff of Inversion	Duration of Haze Event
08 Dec 04/ Wed	800 mb 670	50 mb 15 mb	0° (isothermal) 1	All day
09 Dec 04/ Thu	800 575	10 25	3 1	Sunrise - 9 am
10 Dec 04/ Fri	855 650 600	10 20 20	2 0 0	Sunrise - 9 am
22 Jan 05/ Sat	750 510 370	20 10 20	0 0 0	Sunrise - 11 am
14 Feb 05/ Mon	800 740	30 30	0 1	All day
11 Dec 04/ Sat	None	-	-	None
05 Feb 05/ Sat	750 680 440	10 30 30	0 0 0	None
26 Feb 05/ Sat	None	-	-	None

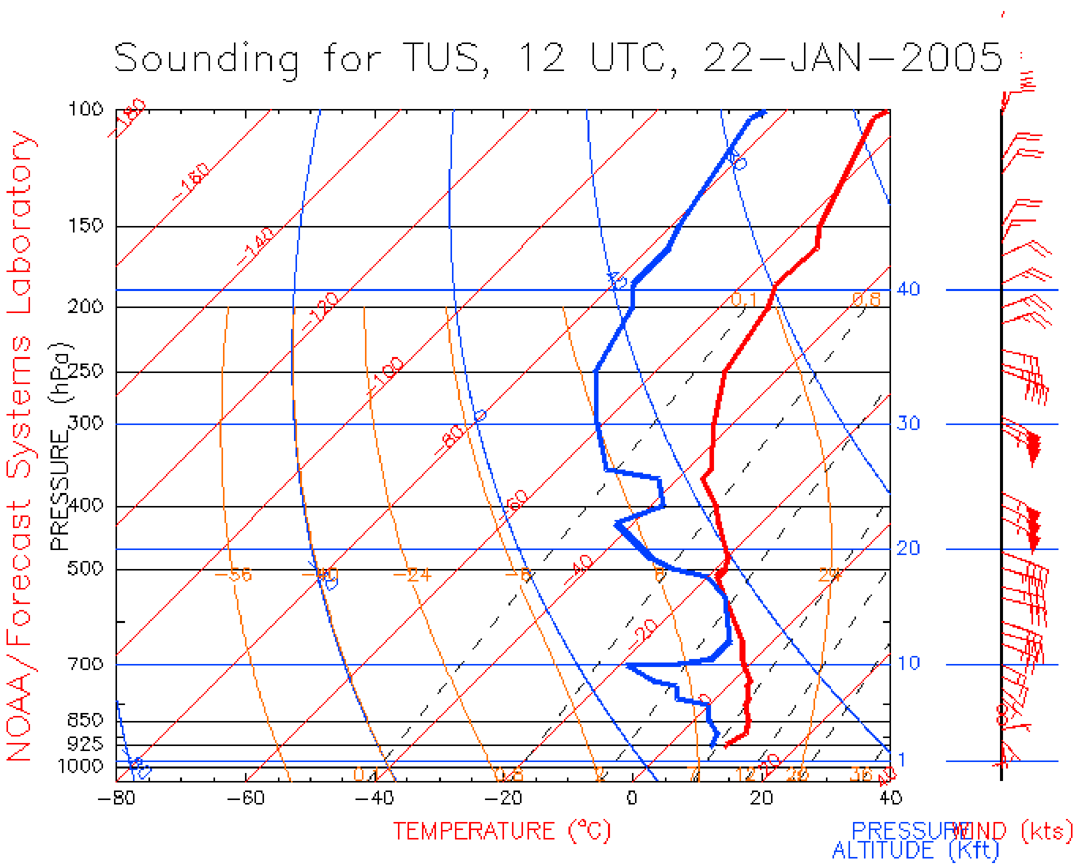

Figure 6. Tucson sounding for January 22nd, 2005 at 12z. Note the several inversion layers, and the moist layers.

Temperatures

The temperature-dew point spread at the surface was less than 8 degrees Celsius, or 14° Fahrenheit in the observations taken before the haze diminished. Of the haze days studied, the haze dissipated by 11 am in three of the events. In these cases the sun angle may have overcome the atmospheric moisture making the reflection less of a problem. Two of five events had the haze problem redevelop in the afternoon near sunset. The angle of the sun had returned to a perfect reflecting angle.

Additional Observations

On the 26th of February, 2005 a deep layer of moisture was evident, on both of the Phoenix and Tucson soundings. The Tucson sounding had several inversions, however, no reports of visual problems were received. An additional item not yet considered was the day of the week. Traffic within the city on the weekends is a fraction of what it is on weekdays, thus likely reducing the haze beneath the inversions. Less pollution would mean less of a chance of visual problems.

On the December 11th, 2004 Phoenix and Tucson had an inversion near the surface. The conditions seemed the same as those of the 10th. The rest of the atmosphere was dry and yet on the 10th there were visual problems. What might have made the difference? The 10th was a Friday, a day when traffic may still have been bad enough to cause problems just for the few hours before the inversion broke. The 11th was a Saturday with less traffic. Additionally, the winds just off the surface were about 10 kt stronger than those on December 10th.

February 05th, 2005 was another case where haze was expected but no reports were received. On this day several inversions existed but again it was a Saturday and may have been a day with little traffic. On the 26th of February, 2005 (discussed above) only one inversion layer existed but the atmosphere was moist to 700 mb. The 26th was also a Saturday.

The amount of particulates in the air might also contribute to the elevated haze problem. Concentrations above 50 parts per million (ppm) are considered a "Moderate risk" to health, and values greater than 100 ppm fall in the "Unhealthy for Sensitive Groups". On December 8th thru the 11th, 2004 a Stagnation Advisory was issued for Phoenix. Coarse particulate matter or PM_{10} for each of those days ranged from 55 to 79. For the remainder of the days in this study, the values were less than 50. Fine particulate matter or $PM_{2.5}$, Ozone, and Carbon Monoxide values were also examined but found to all be within safe values or less than 50.

Conclusions

Elevated haze occasionally occurs in Phoenix during the winters. On some of these days pilots flying into Sky Harbor Airport have a difficulty seeing the runway, causing air traffic problems because of the haze layer(s). The tower can accept 72 planes an hour on a clear day when there are no visibility restrictions. On a hazy day, the acceptance rate may go down to 32 planes.

Light northwesterly flow occurred in three of the five cases. A second pattern had a low over northern Baja Gulf. In all cases winds less than 15 kt were in the soundings at 850 and 700 mb. At the surface the winds were less than 10 kt.

Precipitation was not recorded at the Phoenix airport prior to each event but interpolated soundings of Phoenix, and sounding taken from Tucson indicate a somewhat moist layer to at least 800 mb. A dew point depression of 7°C or greater at the surface seemed to be the cutoff for a haze-problem day which may be coincidental with the time of day. Sun angles in the morning, and late afternoon hours are perfect for sunlight to be reflected back into the eyes of the pilots. Three or more inversions are significant, and all the days studied had at least three.

Sometimes haze is evident in the mornings but does not cause problems for pilots. In these cases, the lack of reported visibility restrictions due to haze may be due to cloud cover or low moisture content aloft. The day of the week may also play a role. Documented haze events in this study did not occur on Saturday or Sunday except for January 22nd. On three weekend days which appeared to have favorable conditions for elevated haze, no reports were received. Concentrations of coarse particulate matter (PM_{10}) were found to be in moderate values for half of the events.

Haze density can be worsened if strong winds (>25 kt) prior to the haze day have occurred. In all of these events the winds were found to be less than 20 kt for a peak gust, and less than 10 for an average speed the day(s) before.

Acknowledgements

Thanks to Deirdre Kann, the Science and Operations Officer at WFO Albuquerque, for her suggestions, help with graphics, and proofreading of this paper. Thanks to Brent Wachter, WFO Albuquerque, for his suggestions. Lastly, thanks to Larry Braaten of Albuquerque's Air Traffic Control Center Traffic Management Unit for all the information on the Phoenix traffic situations.

References:

An Overview of Phoenix Climate. Robert J. Schmidli, Office of Climatology, Arizona State University. 1996. http://geography.asu.edu/cerveny/phxwx.htm.
http://geography.as.edu/cerveny/wxpart4.htm#fw2

Arizona Department of Environmental Quality.
http://www.azdeq.gov/environ/air/index.html.
http://www.azdeq.gov/function/forms/docs.html#month
http://www.azdeq.gov/environ/air/monitoring/download/1204.pdf

Phoenix Weather Forecast Office Staff.

Pilot/Controller Glossary. Order 7110.10S of Flight Services. February 16, 2006.

Global Systems Division (GSD) of Earth System Research Laboratory (ESRL) (formerly Forecast Systems Laboratory.) http://raob.fsl.noaa.gov

Graphics depicted in Fig. 2, 3, 4, and 5 were generated at NOAA's Climate Diagnostic Center website. http://www.cdc.noaa.gov